Methods Used to Calculate Flood Control Benefit of CVP Storage Facilities

Analysis of Reclamation Storage Facilities Sizing for the Single Purpose of Flood Control

The Central Valley Project Cost Allocation Study requires the development of information quantifying the contribution of each project facility to overall project benefit. One approach to this analysis is to operate facilities as if they were providing only a single purpose. The application of this approach to the flood control purpose answers the question "If the sole purpose for a storage facility was to provide flood control protection, how large would it have to be?" Two separate analysis methods were used to develop answers to this question. Details of each method are presented in this document. Study results and decisions are discussed in the summary.

Flood Control Rule Method

A flood control rule limits the volume of water that may occupy space in a reservoir, effectively mandating that a certain amount of empty space be maintained in order to accommodate anticipated seasonal runoff. Figure 1 provides a conceptual diagram. Flood control rule curves are the time-varying values for flood control rules through the water year. Space requirements are typically highest in the late winter and may vary annually depending on runoff forecasts for the reservoir catchment area. A high space requirement translates to a lower rule curve. Rule curves through the rest of the year depend on operating strategies and flood risks of individual storage facilities. Limits are set by the Army Corps of Engineers or other local flood protection authorities. Figure 2 shows a portion of the historical flood control rule curve for Folsom Lake, as used by the CalSim2 planning model.

Figure 1 – Flood Control Rule Concept

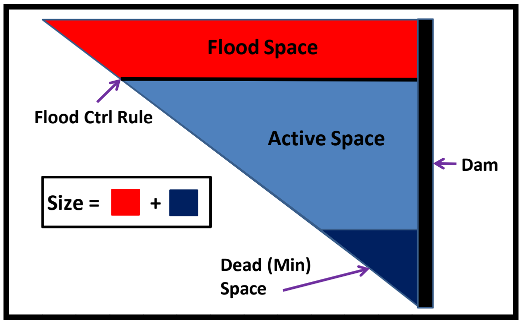
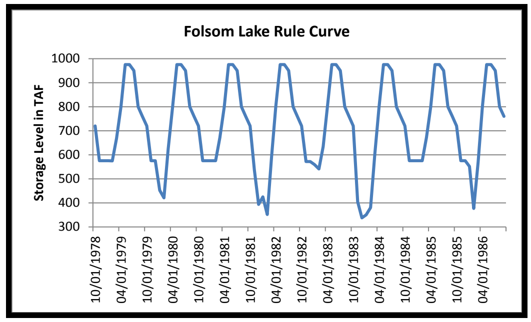


Figure 2 – Flood Control Rule Curve Example



The flood control rule method for determining the size of a reservoir is simply to select the largest value for required flood space in a reservoir from the historical flood control diagrams. This approach does not provide a pure single-purpose or single-facility perspective, however, as the historical trace of required space in a reservoir has typically considered normal operations such as releases for water supply deliveries, flow standards, and other criteria, as well as the integration of that facility's operations with other facilities in the system.

To apply this method, the time series of flood control rules used in the CalSimII planning model were scrutinized to find the minimum value. This minimum was subtracted from the storage capacity of the reservoir to define the maximum required flood space. This is then added to the minimum operating storage level in the reservoir to calculate the size of the reservoir for the single purpose of flood control. Table 1 provides a summary of sizing results produced by this method.

Table 1 – Flood Control Rule Method Results - all values in TAF

	Minimum Flood Control Rule	Storage Capacity	Flood Space Required	Minimum Storage (Dead Pool)	Single Purpose Reservoir Size
Shasta	3250	4552	1302	550	1852
Folsom	305	975	670	90	760
New Melones	1970	2420	450	80	530
Millerton	350.5	524	173.5	135	308.5

Daily Hydrology Modeling Method

The second method was to use a daily hydrology modeling approach to depict the operation of each facility under the assumption that its sole purpose was to provide flood control. A spreadsheet model template was developed and then applied to each of the CVP reservoirs with an authorized flood control purpose – Shasta, Folsom, New Melones, and Millerton. Input data to each model includes:

- Inflow – historical daily inflow for each reservoir, provided by the Central Valley Operations (CVO) office
- evaporation rate – since lengthy daily time series records of evaporation rates are not commonly available, monthly evaporation rates used by the CalSim2 planning model were converted to average daily rates and applied to the previous day's reservoir surface area to calculate daily evaporation
- storage/discharge and head/area/capacity curves – the daily model used data from the CalSim2 planning model
- accretions between the dam and a downstream control point – historical daily accretions were developed from historical daily flows accessed at the California Data Exchange Center (CDEC)
- flow threshold criteria – limits on reservoir releases and/or flows at downstream locations

The accuracy of daily hydrology model results is affected by some key assumptions used for all of the reservoirs studied. These are described below. For all of these assumptions, the level of accuracy attained by this analysis is well within the range sufficient for informing the facility cost estimates that drive the Cost Allocation Study process.

First, reservoir routing was not used in the analysis. The rationale for this is that reservoir operations would be more highly managed during extremely wet hydrologic events, so the effect of routing on the determination of maximum reservoir size is unlikely to be significant. Routing would be more of an issue at lower storage levels, where the combined effects of lag time and stage/discharge relationship would play a prominent role in determining pass-through flows. This study is only concerned with the highest storage levels.

Second, local accretions between the dam and a downstream location, which inform limits on reservoir release, are not unimpaired. They include the effects of historical diversions in that river reach. However, it is assumed that diversions are not likely to be significant during extremely wet hydrology events, so the use of these unimpaired flows would not substantially affect the determination of maximum reservoir storage attained.

Finally, previous day's storage is used to compute evaporation loss and discharge capacity. Given that the use of average monthly evaporation rates on a daily basis already introduces an element of error, it is proposed that the use of previous day storage to compute evaporation does not further detract from the level of model accuracy. The discharge capacity is only an issue when it limits reservoir release during the wet period which defines the maximum necessary storage. For each reservoir model, selected wet periods were re-analyzed by determining the potential reservoir release as a function of the current day's storage, using the iterative calculation functionality in Excel. This allowed a better determination of the maximum storage value attained during flood events.

Detailed discussion of the specific model assumptions and results for each storage facility are provided in the following sections. A summary of the reservoir sizing results based on the daily model method is presented in Table 2.

Table 2 – Daily Model Method Results for Maximum Required Storage

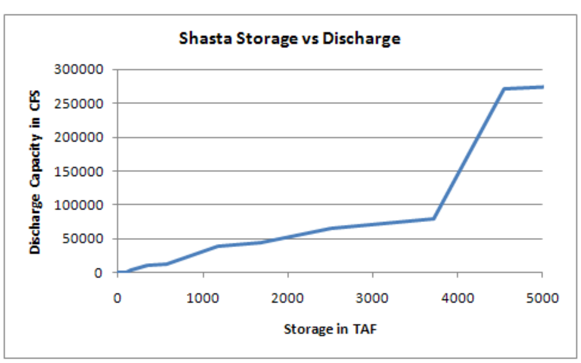
	Period Analyzed	**Max Storage in TAF**
Shasta	1/44 - 9/10	1966.8
Folsom	10/61 - 9/10	573.0
New Melones	7/79 - 9/09	477.5
Millerton	2/44 - 9/10	931.0

Shasta Reservoir Model

Historical daily data for computed inflows to Shasta Lake were available from January 1944 through the present day. CDEC data for daily flows for the Sacramento River at Keswick and for the Sacramento River at Bend Bridge were available from January 1944 through September 2010. This data was used to compute an accretion between Keswick and Bend Bridge. No accretion was assumed between Shasta Dam and Keswick Dam, and no import of water from the Trinity River watershed was included. The availability of flow data determined the period of record for which the analysis was performed – January 1944 through September 2010. CVO operates Shasta Dam to avoid flows above 100,000 cfs on the Sacramento River at Bend Bridge, and also to avoid releases from Keswick Dam that exceed 79,000 cfs.

The daily model run for Shasta Dam starts on January 1, 1944 assuming a minimum regulated storage rule of 550 TAF. Release capacity as a function of reservoir storage is shown in Figure 3. Reservoir release is limited to 79,000 cfs to meet the Keswick constraint. A second release limitation is determined relative to the computed gain between Keswick and Bend Bridge such that resulting flow at Bend Bridge would not exceed 100,000 cfs. Daily storage is determined as : *Previous Day Storage + Inflow – Evaporation – min(79000, min(Release Capacity, 100000-Keswick_to_BendBridge_Accretion)).*

Figure 3 – Shasta Storage vs. Discharge Capacity



Shasta Results

The maximum storage attained in Shasta Lake as a result of the daily hydrology model investigation is 1966.8 taf, occurring in January of 1970. Other extreme inflow events in 1983, 1986, and 1997 resulted in needs for storage capacities of 1583 taf, 1618 taf, and 1824 taf respectively. A time series plot of Shasta inflow, release, and storage is shown in Figure 4a, and an exceedence plot of the same data is shown in Figure 4b. Instances of higher reservoir storage requirements to contain extreme inflow events are evident in the sharp spikes in the green lines in the time series plot. The overall frequency of storage requirement for flood control is about 23%. The 100,000 cfs flow threshold at Bend Bridge controls the operation in 16 days during the period of record. Outlet capacity controls releases at all other times; Keswick never controls as releases are always well under the 79,000 cfs threshold.

Figure 4a – Time Series of Shasta Lake Operation for Flood Control

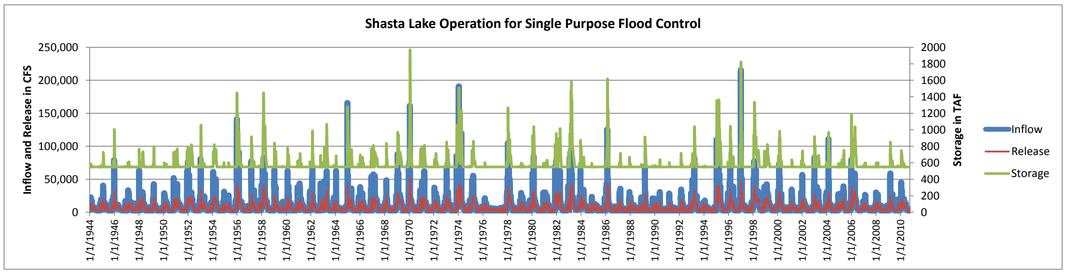
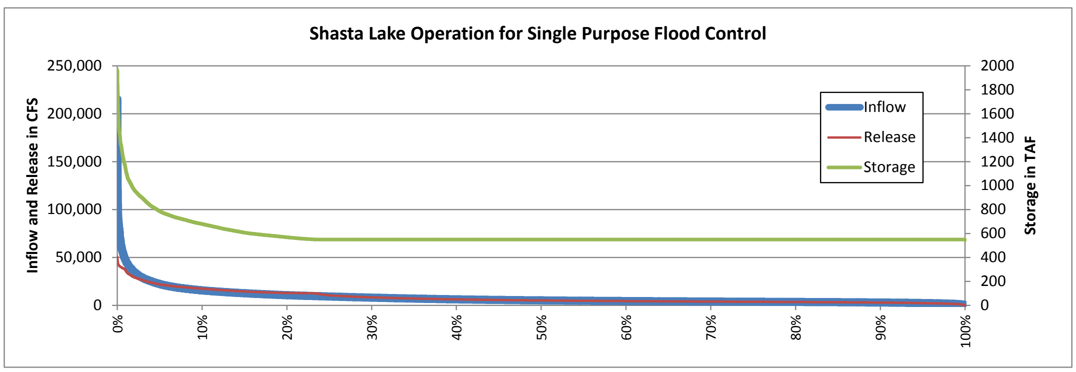


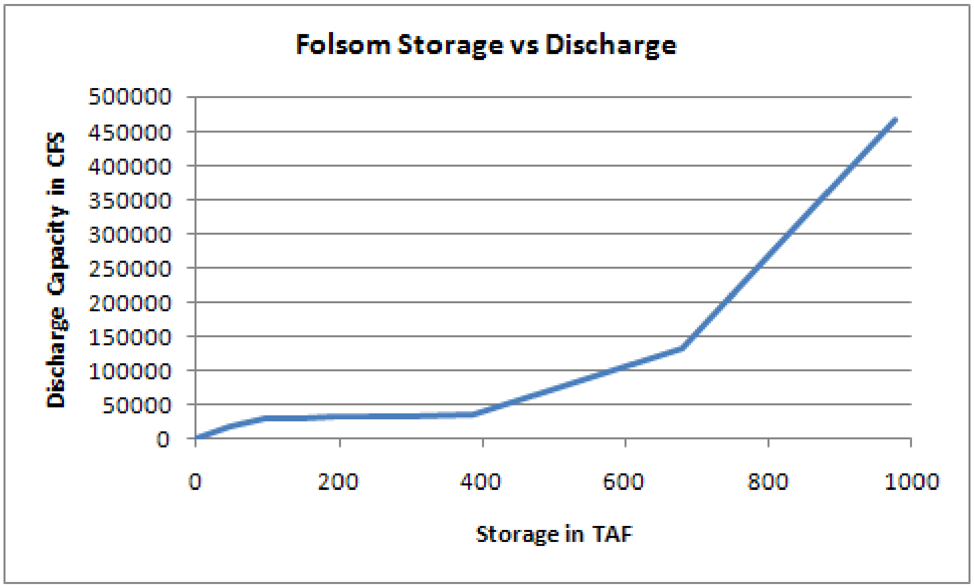
Figure 4b – Exceedence of Shasta Lake Operation for Flood Control



Folsom Reservoir Model

Historical daily data for computed inflows to Folsom was available from October 1961 through the present day. CDEC data for daily flows for the American River at Nimbus and Fair Oaks were available from October 1961 through September 2010. This data was used to compute an accretion between Nimbus and Fair Oaks. No accretion was assumed between Folsom Dam and Nimbus Dam. The availability of flow data determined the period of record for which the analysis was performed – October 1961 through September 2010. CVO operates Folsom Dam to limit releases to 115,000 cfs. American River at Fair Oaks is also a flood control point where it is desired to keep flows to a maximum of 115,000 cfs, but this is not a Reclamation mandate and is not included in the study constraints. The daily model run for Folsom starts on October 1, 1961 assuming a minimum regulated storage pool of 90 TAF. Outlet works capacity as a function of reservoir storage is shown in Figure 5. Reservoir release is limited to 115,000 cfs to satisfy the release constraint at the dam.

Figure 5 – Folsom Storage vs Discharge Capacity



Folsom Results

The maximum storage attained in Folsom Reservoir as a result of the daily hydrology model investigation is 573 taf, occurring in February of 1986. Other extreme inflow events in 1963, 1964, and 1997 resulted in needs for storage capacities of 444 taf, 564 taf, and 572 taf respectively. A time series plot of Folsom inflow, release, and storage is shown in Figure 6a, and an exceedence plot of the same data is shown in Figure 6b. Instances of higher reservoir storage requirements to contain extreme inflow events are evident in the sharp spikes in the green lines in the time series plot. The overall frequency of storage requirement for flood control is less than 2%. The outlet works capacity at Folsom controls at all times, and releases never exceed 115,000 cfs since the storage level never gets high enough to allow that level of discharge.

Figure 6a – Time Series of Folsom Lake Operation for Flood Control

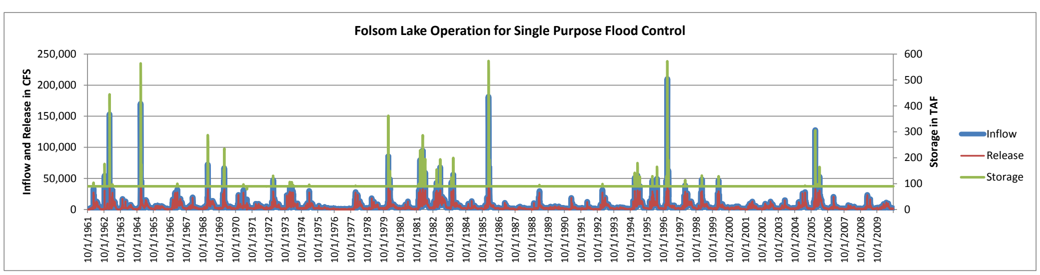
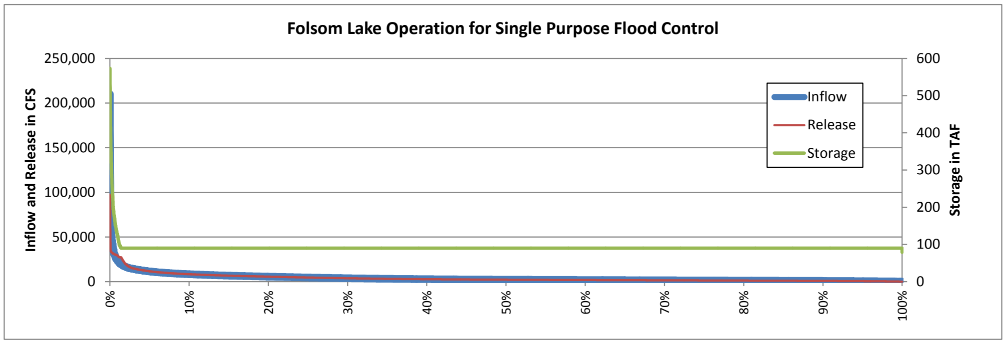


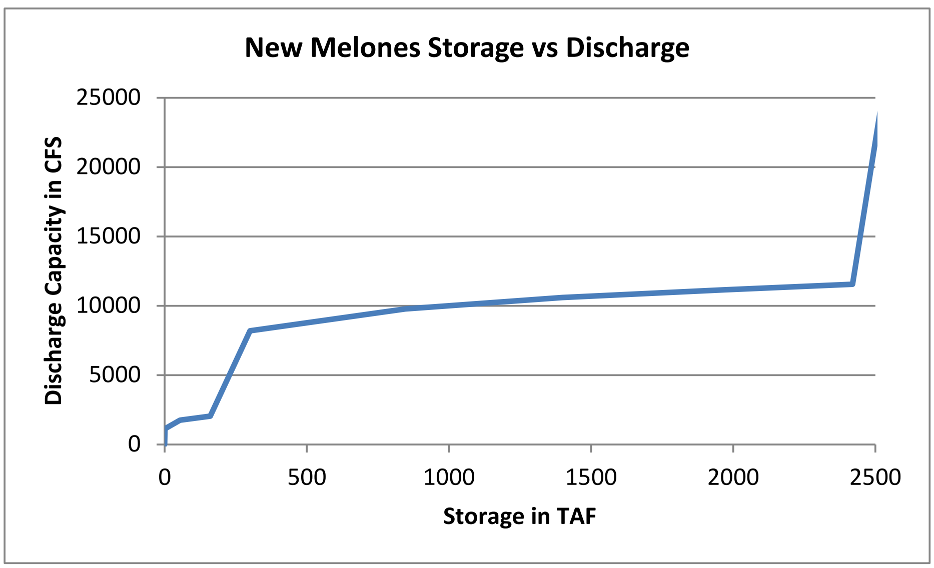
Figure 6b – Exceedence of Folsom Lake Operation for Flood Control



New Melones Model

Historical daily data for computed inflows to New Melones was available from July 1, 1979 through the present day. USGS gage data for daily flows at Goodwin and Ripon were available through September 2009. This data was used to compute an accretion between New Melones and Ripon. No accretion was assumed between New Melones and Goodwin. The availability of flow data determined the period of record for which the analysis was performed – July 1979 through September 2009. CVO operates New Melones Dam to limit releases to 8,000 cfs, and to not let flows at Ripon exceed 8,000 cfs. The daily model for New Melones starts on July 1, 1979 assuming a minimum regulated storage pool of 80 TAF. Outlet works capacity as a function of reservoir storage is shown in Figure 7. Reservoir release is limited to 8,000 cfs or to 8,000 minus the accretion between Goodwin and Ripon.

Figure 7 – New Melones Storage vs Discharge Capacity



New Melones Results

The maximum storage attained in New Melones Reservoir as a result of the daily hydrology model investigation is 477 taf, occurring in June of 1983. Other extreme inflow events in 1986 and 1997 resulted in needs for storage capacities of 334 taf and

432 taf respectively. All other instances of higher storage need were less than 300 taf. A time series plot of New Melones inflow, release, and storage is shown in Figure 8a, and an exceedence plot of the same data is shown in Figure 8b. Instances of higher reservoir storage requirements to contain extreme inflow events are evident in the sharp spikes in the green lines in the time series plot. The overall frequency of storage requirement for flood control is 37%. The Ripon flow constraint and the dam release constraint share control of the releases through the high inflow events.

Figure 8a – Time Series of New Melones Reservoir Operation for Flood Control

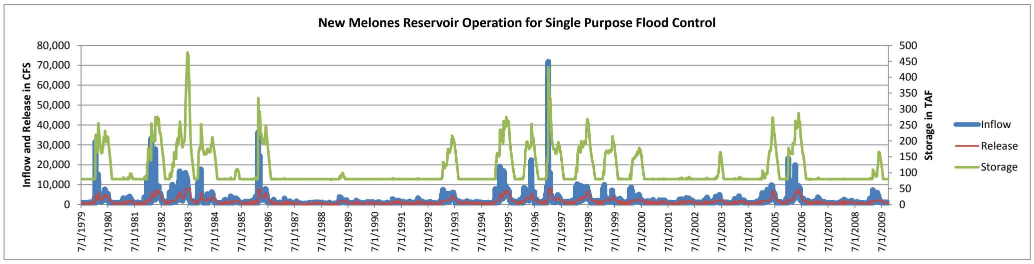
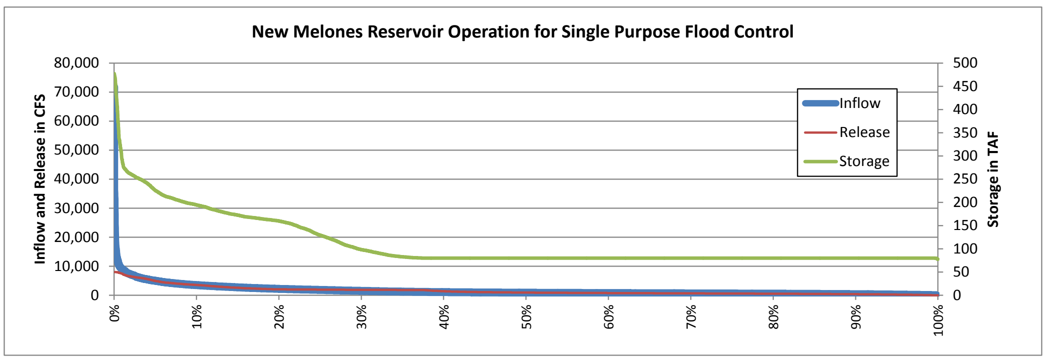


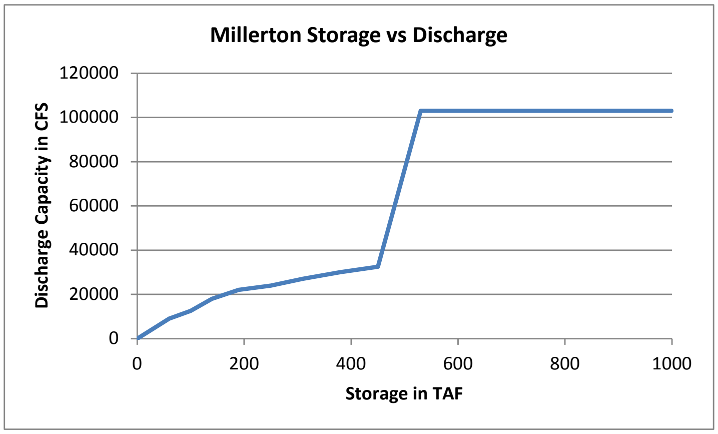
Figure 8b – Exceedence of New Melones Reservoir Operation for Flood Control



Millerton Model

CVO provided daily historical data for computed inflows to New Melones from February 22, 1944 through the present day. For consistence with the other reservoir sizing studies, the period of record was chosen to end in September 2010. Millerton Lake has a small storage capacity relative to its average annual inflow, and it does fill and release snowmelt runoff in most years. CVO ideally operates Friant Dam to limit releases to 8,000 cfs, although the historical record shows instances of much higher flows. For the purposes of the current study, releases were capped at 9,000 cfs. The daily model for Friant Dam begins on February 22, 1944 assuming a minimum regulated storage pool of 135 TAF. Outlet works capacity as a function of reservoir storage is shown in Figure 9.

Figure 9 – Millerton Storage vs Discharge Capacity



Millerton Results

The maximum storage attained in Millerton Lake as a result of the daily hydrology model investigation 931 taf, occurring in June of 1983. Other extreme inflow events in 1965 and 1995, and 2006 resulted in needs for storage capacities of 684 taf, 472 taf, and 452 taf respectively. A time series plot of Millerton inflow, release, and storage is shown in Figure 10a, and an exceedence plot of the same data is shown in Figure 10b. The storage requirement for fully constraining reservoir releases to 9,000 cfs is nearly twice the size of the actual reservoir. An additional analysis was performed to find that if the reservoir size was not increased, the highest release would be nearly 13,000 cfs, and in fact this level of release has been reached or exceeded upon several occasions in operating history.

Figure 10a – Time Series of Millerton Lake Operation for Flood Control

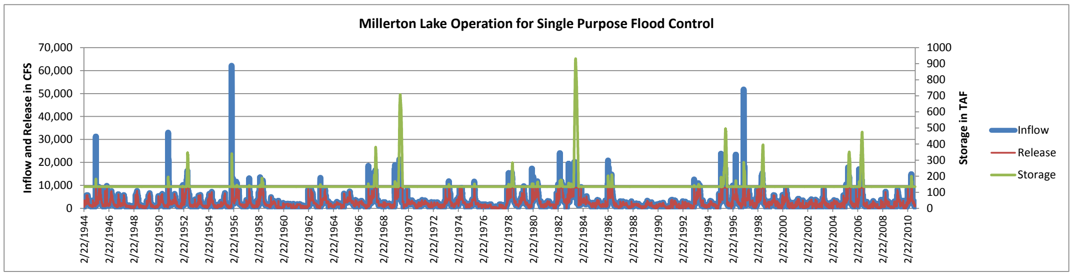
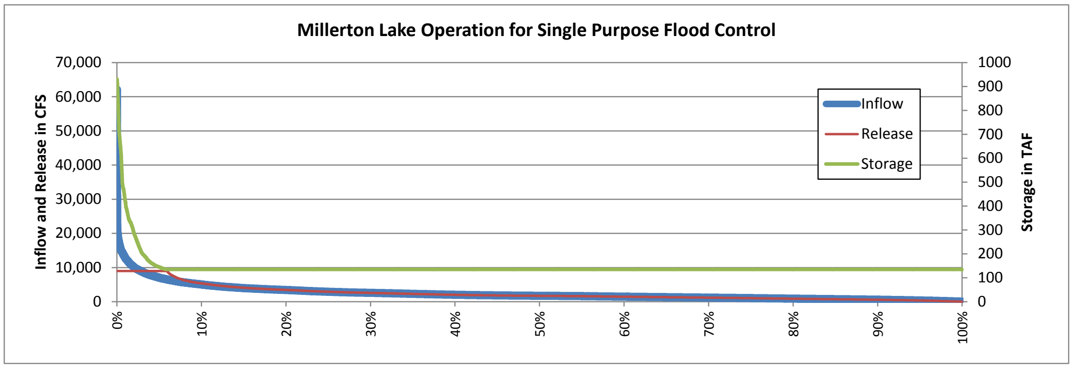


Figure 10b – Exceedence of Millerton Lake Operation for Flood Control



Study Summary – Reservoir Sizing for Flood Control Purpose

Table 3 below summarizes the overall results of the two approaches for determining the single purpose reservoir sizing for meeting the flood control purpose of CVP reservoirs.

Table 3 – Single Purpose Reservoir Sizes in TAF – Flood Control Purpose

	Flood Control Rule Curve Method	Daily Hydrology Model Method
Shasta	1852	1967
Folsom	760	573
New Melones	530	478
Millerton	309	931

The Cost Allocation Study Team has examined the results for reservoir sizing under both the flood control rule curve method and daily hydrology model method. Both methods are analytically sound, and have good arguments for use:

- Rule Curve Method
  - Best reflection of actual flood control purpose due to inherent consideration of operations
  - Self-limiting – i.e. not affected by outlier events which exceed the scope of project intent
- Daily Model Method
  - Best reflection of pure single-purpose flood control size requirement

It is desirable to use one consistent approach for all reservoir sizing, and the Cost Allocation Study Team has elected to proceed with costing for sizes generated by the flood control rule curve method. Most clearly, this avoids the issue with the daily model size for Millerton Lake exceeding its current size.